Fundamentals of modern Manufacturing

Metal Casting

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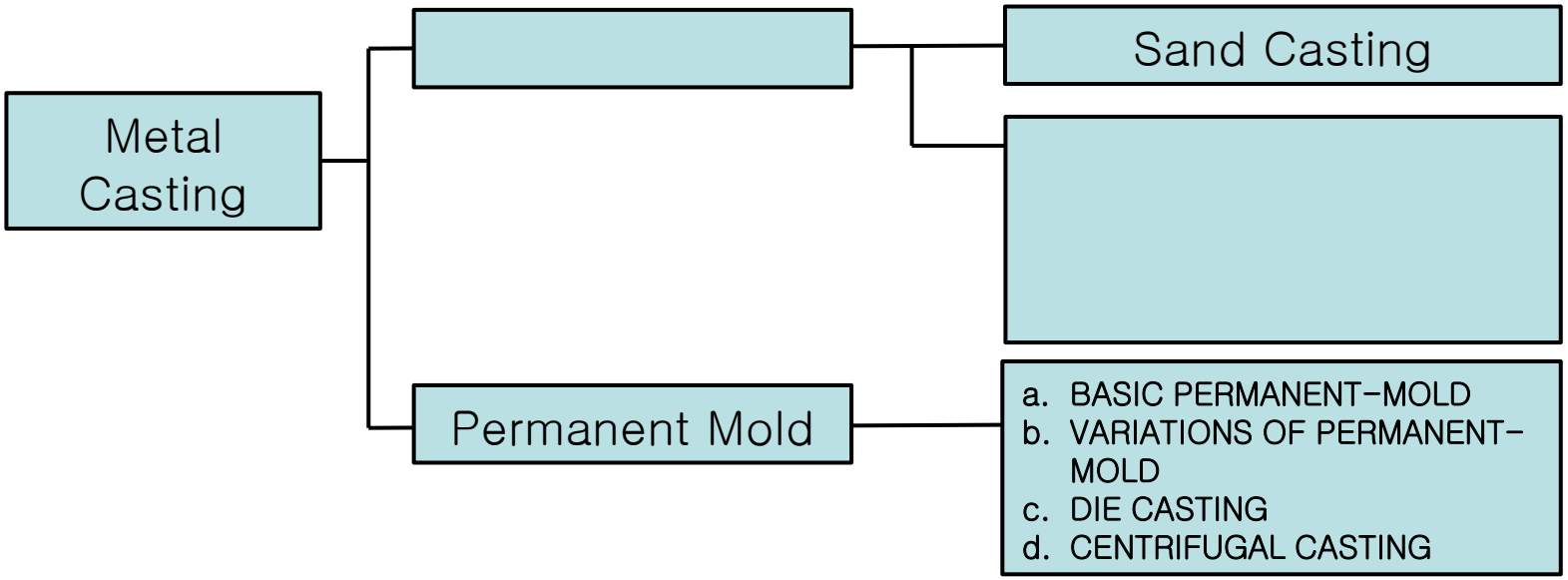
1. What is Casting?

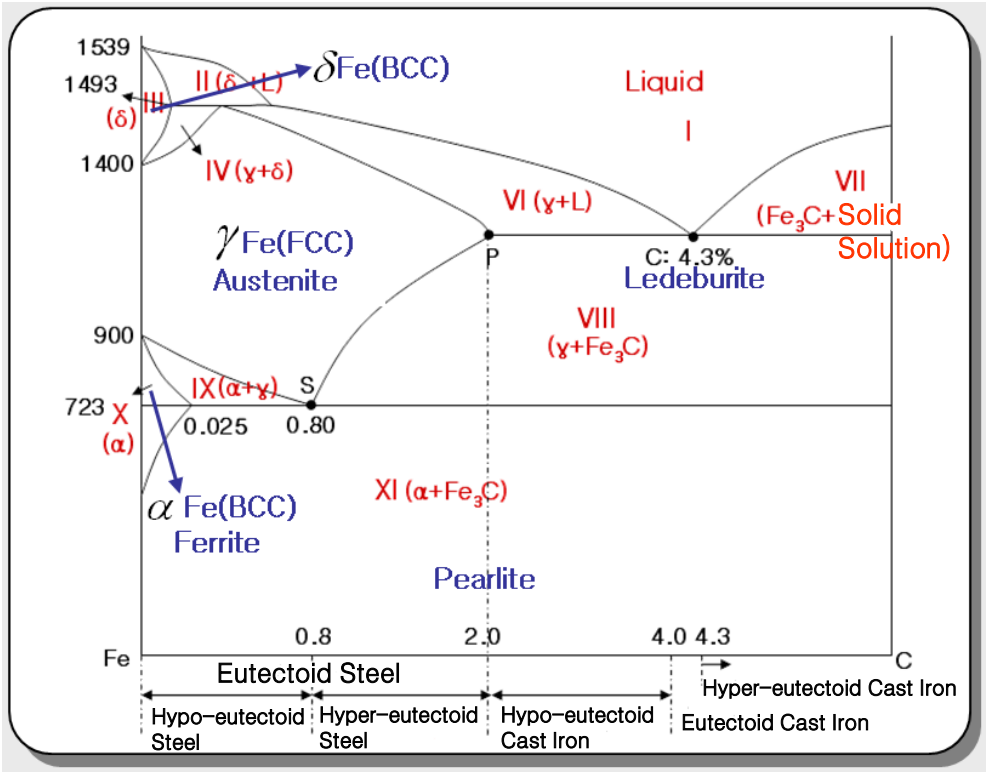
- Casting is a manufacturing process by which a liquid material is usually poured into a mold that contains a hollow cavity of the desired shape, and then allowed to solidify.
- An expendable mold means that the mold in which the molten metal solidifies must be destroyed in order to remove the casting.



◇ Phase Diagram

- Casting is a manufacturing process by which a liquid material is usually poured into a mold that contains a hollow cavity of the desired shape, and then phase diagram is basically consisted of temperature and concentration ratio.

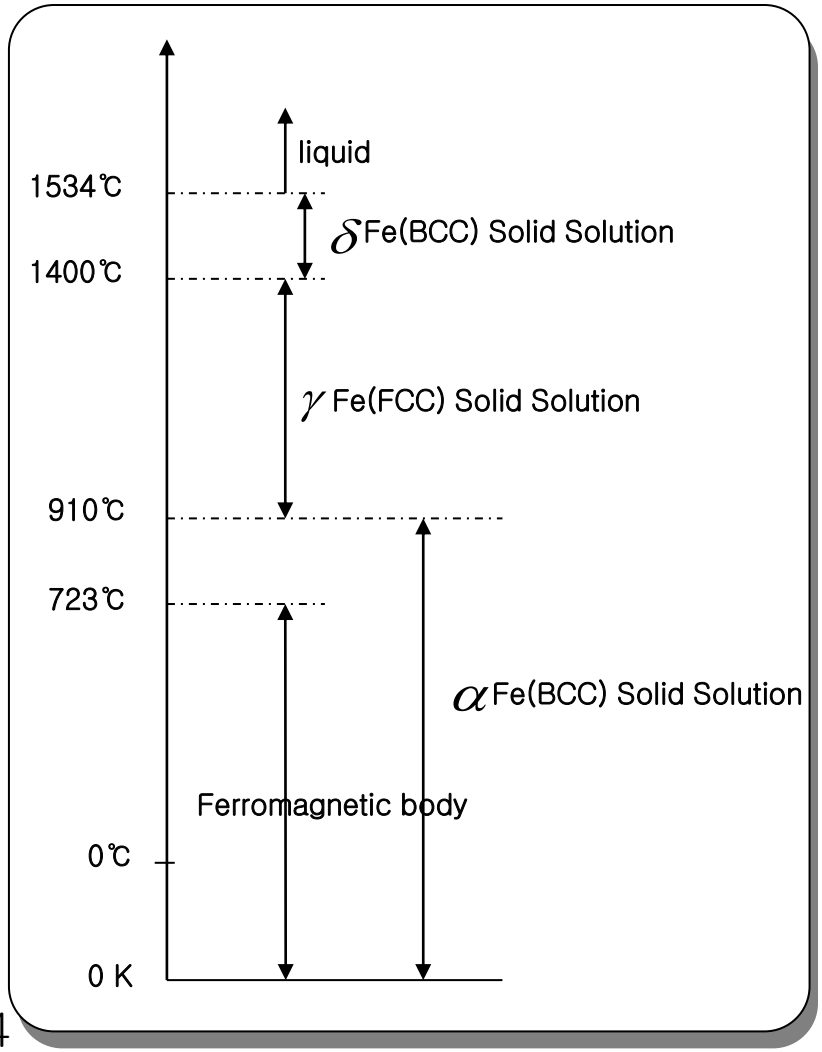
  Ex) Fe-C Phase Diagram



- Solution of C atom α Fe : Ferrite
- Solution of C atom γ Fe : Austenite
- Cementite : C content 6.67% ($Fe_3C = \frac{12}{56\times3+12}\times100 = 6.67\%$)

- semi-stable compound → Hardness is higher but toughness is poor(similar glass), reduction of Fe and Graphite by heating.

◇ Transformation of Iron



※ At every transformation point, physical properties are changed

→ Coefficient of Thermal Expansion, Specific heat, Magnetism

◇ Peritectic reaction

- Peritectic transformations are also similar to eutectic reactions. Here, a liquid and solid phase of fixed proportions react at a fixed temperature to yield a single solid phase.

※ at 1493℃

Solid Component of δ Phase: (1)

Liquid Component of γ Phase : (2)

Solid Component of L Phase :
(3) existence, C:0.51%

- In this composition, occurrence reaction is Peritectic reaction, this temperature(1493℃) is Peritectic point at this moment.
- C content 4.30%(1147℃, Fe-C phase diagram on C point) eutectic composition, 1147℃ Eutectic point
- generated structure by eutectic reaction : Ledeburite
- generated structure under 723℃ : Pearlite

◇ Solidification of Castings

1) Solidification time of Castings

- Metal Mold : 4~10min.

- Sand Casting : 30~90min.

2) Centerline Feeding Resistance

$$CFR = \frac{crystallized\ time\ of\ center's\ Castings}{Total\ time\ of\ Castings} \times 100$$

- Metal Mold : 3~20%

- Sand Casting : 30~90%

2.Casting Materials

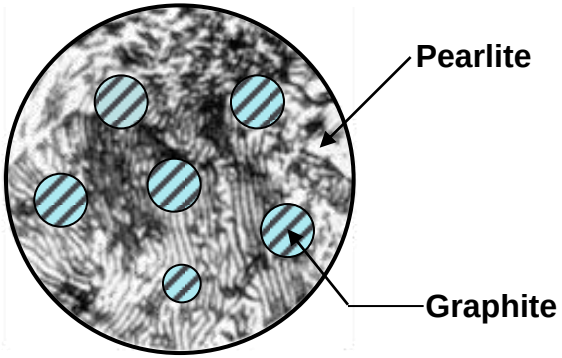
2.1 special Casting

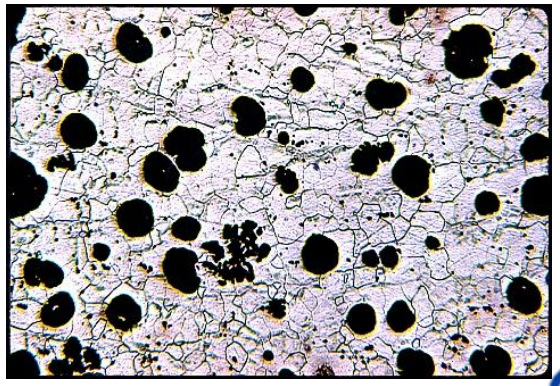
- Invited for demand strong cast iron (1925~1940year)
- Tensile strength :25~ 35 kg/mm^2 high strength, wear resistance, thermal resistance, almost pearlite crystals

2.1.1 Nodular Cast Iron 球狀黑鉛鑄鐵

- Addictive is Ce (Cerium), Si-Mn-Ce-Zr(Zirconium) alloy → too expensive
- After 1950s, Ca, Li, Na, Be, Sr, Zn, Sb added Nodular Cast Iron
- Main ingredient (C:3.5%, Si:2.5%, Mn:0.5%, P:0.05% less, S:0.01%less)
- Mechanical property : Tensile strength: 40~70kg/mm
- elongation: 5~20%
- hardness(HB): 220~230

→ It has a lot of applications





< Black heart Malleable Cast iron >

2.1.2 Malleable Cast Iron ;可鍛鑄鐵

- Main ingredient (C:2.4~2.8%, Si:0.6~1.1%, Mn:0.2~0.4%, P:0.1~0.2%, S:0.05%↓)
- Type of Malleable Cast Iron

1) : BMC 28~37

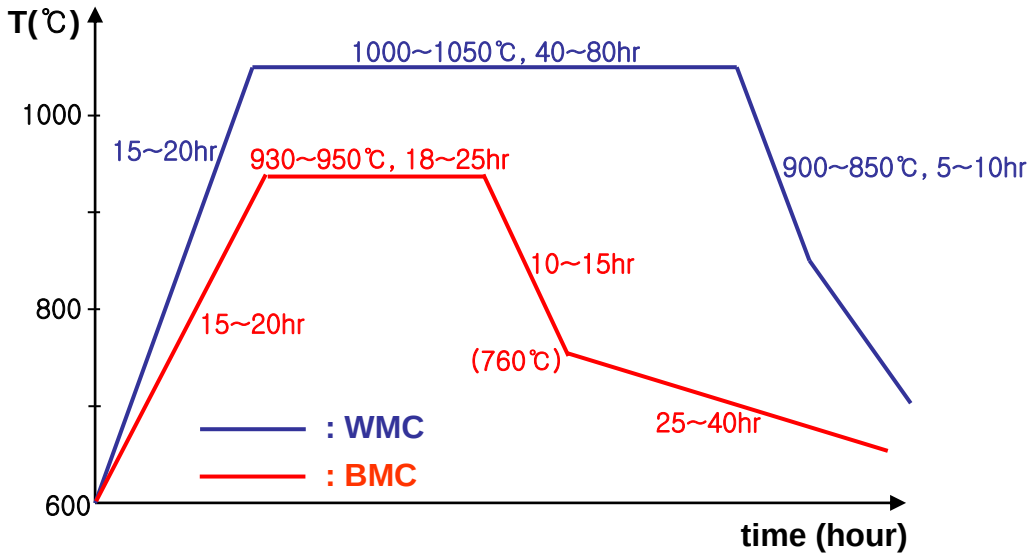
(1) Pre-heating (20~25 hour)
(2) Heating (18~25 hour) & Cooling (25~40 hour)
- Cementite (semi-stable) → Temper Carbon
- Cementite → Austenite → Pearlite

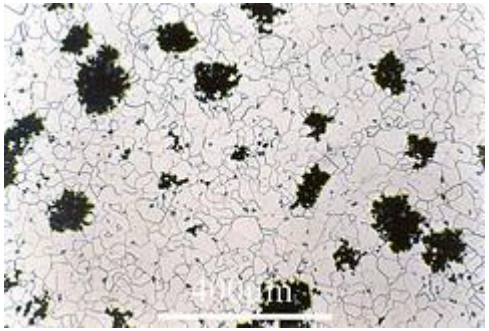
2) : WMC 34~38

(1) Pre-heating (Rising time:15~20 hour, 1000~1050℃)
(2) Heating (constant 40~80hour,1000~1050℃)
- Graphite disassemble → Fe +
- Iron Oxide disassemble → Fe + Graphite ($2Fe_2O_3 + 3C \rightarrow 4Fe + 3CO_2$)
  (Austenite → Pearlite)

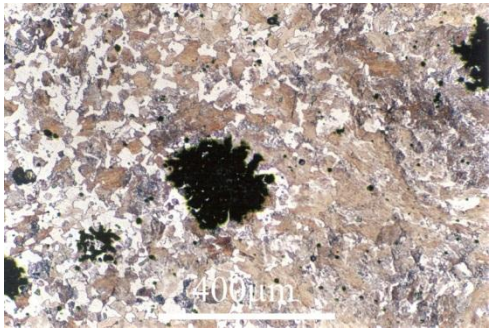
3 : PMC 45~70

※ Malleable cast iron heat treatment process





Black heart Malleable Cast iron

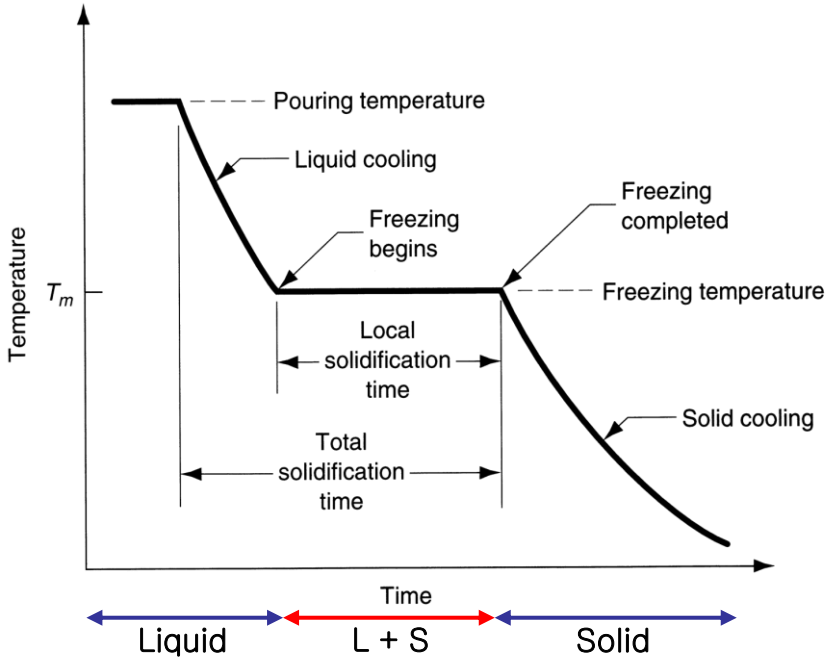


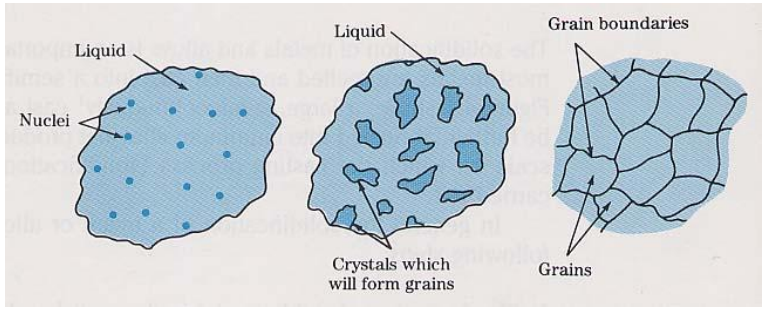
White heart Malleable Cast iron

3. Solidification and Cooling

3.1 Nucleation

- Nucleation means a certain phenomenon which is transformed liquid phase to solid phase. Meanwhile, there is boundary phase between liquidus and solidus during isothermal solidification process. Some examples of phases that may form nucleation that liquid transformed to solid such as crystals or glassy regions.





Nucleation Process

3.1.1 Homogeneous nucleation(Cooling of a pure metal)

- In case of homogeneous nucleation, generally occurs without temperature change during freezing process. It means nucleation of pure metal such as uniform substance.

3.1.2 Heterogeneous nucleation(Cooling of alloy metals)

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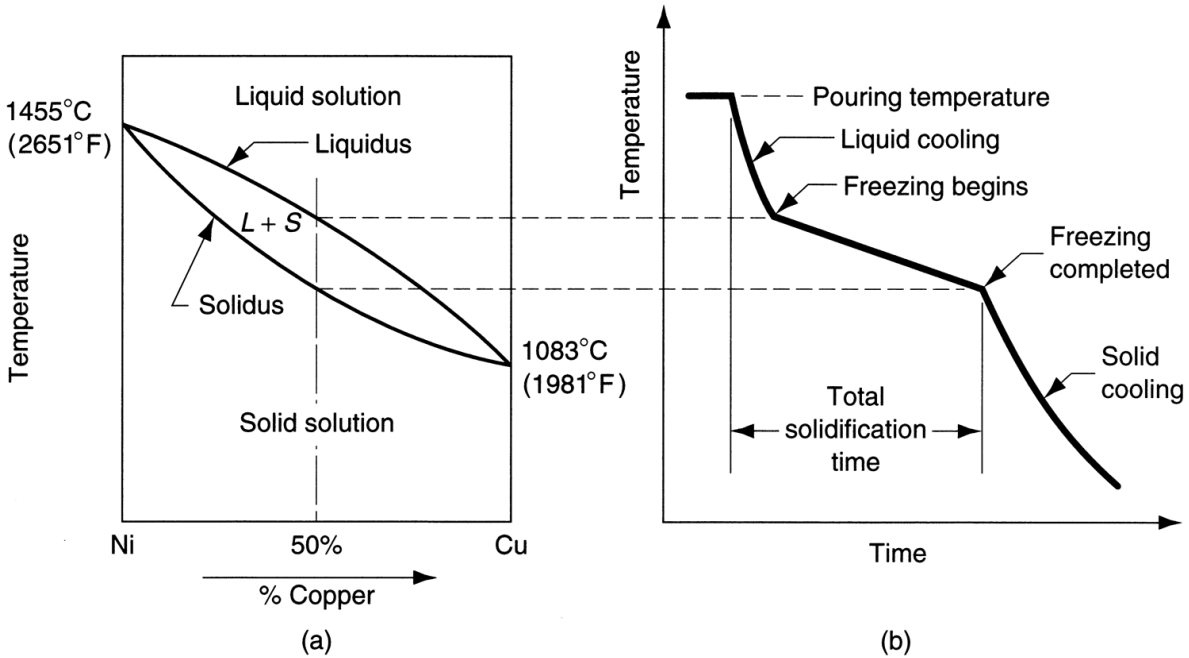


※ The metal which forms the initial skin has been rapidly cooled by the extraction of heat through the mold wall. Chilling zone makes nucleation, This rapid cooling process causes to prevent the grains growth at the outside in alloy. Remaining molten alloy is deprived of that component at the interior.

→ Thus, it means general segregation.

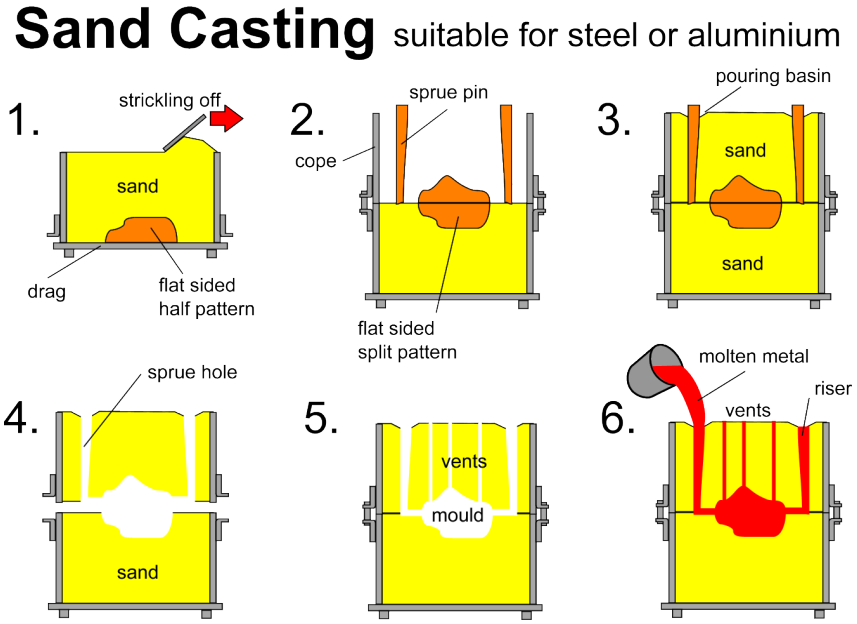
(a) Nucleation , Fine size grain
(b) Is more fast growth rate than (a) ; Dendrite

4. Metal Casting Process

4.1 Expendable Mold

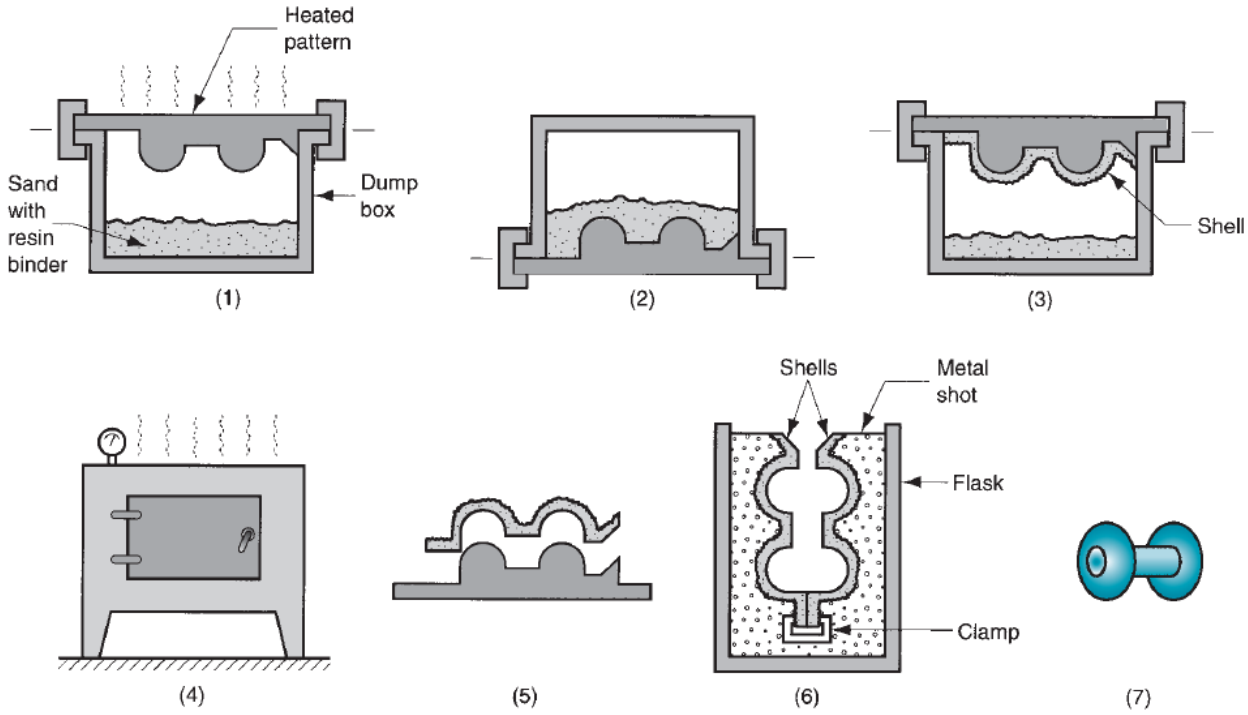
4.1.1 Sand Casting

- most widely used casting process, accounting for a significant majority of the total tonnage cast
- consists of pouring molten metal into a sand mold, allowing the metal to solidify, and then breaking up the mold to remove the casting.



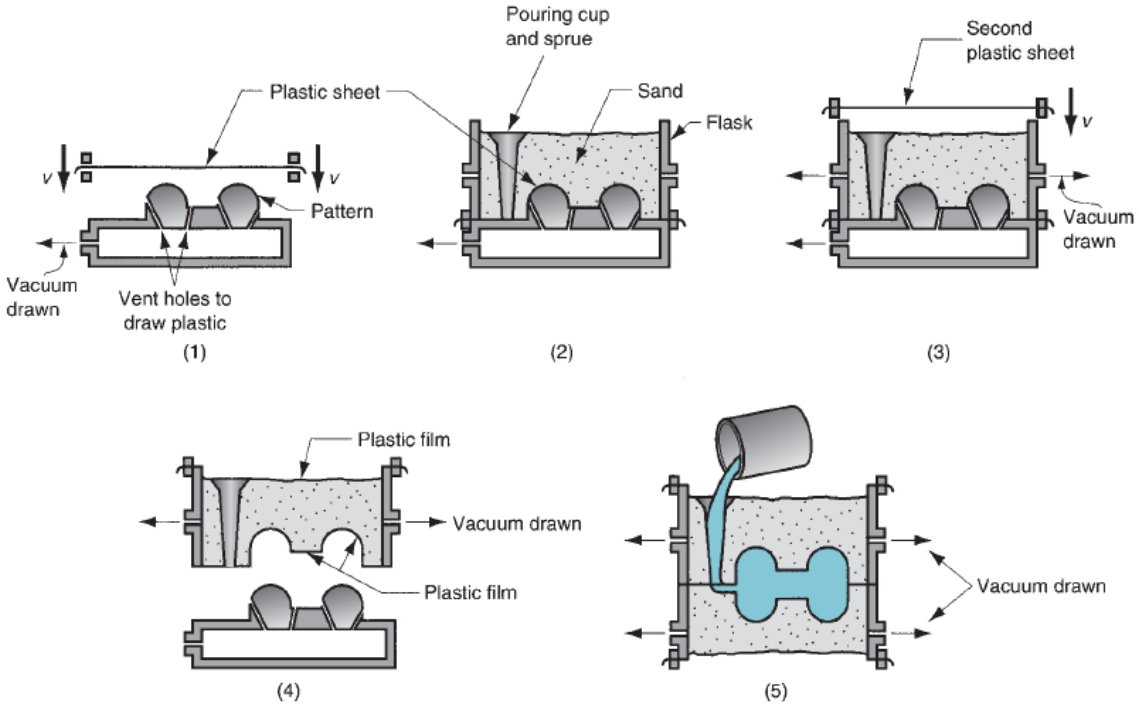
4.1.2 Shell Molding

- The mold is a thin shell (typically 9 mm or 3/8 in) made of sand held together by a thermosetting resin binder.
- The surface of the shell mold cavity is smoother than a conventional green-sand mold
- This smoothness permits easier flow of molten metal during pouring and better surface finish on the final casting.



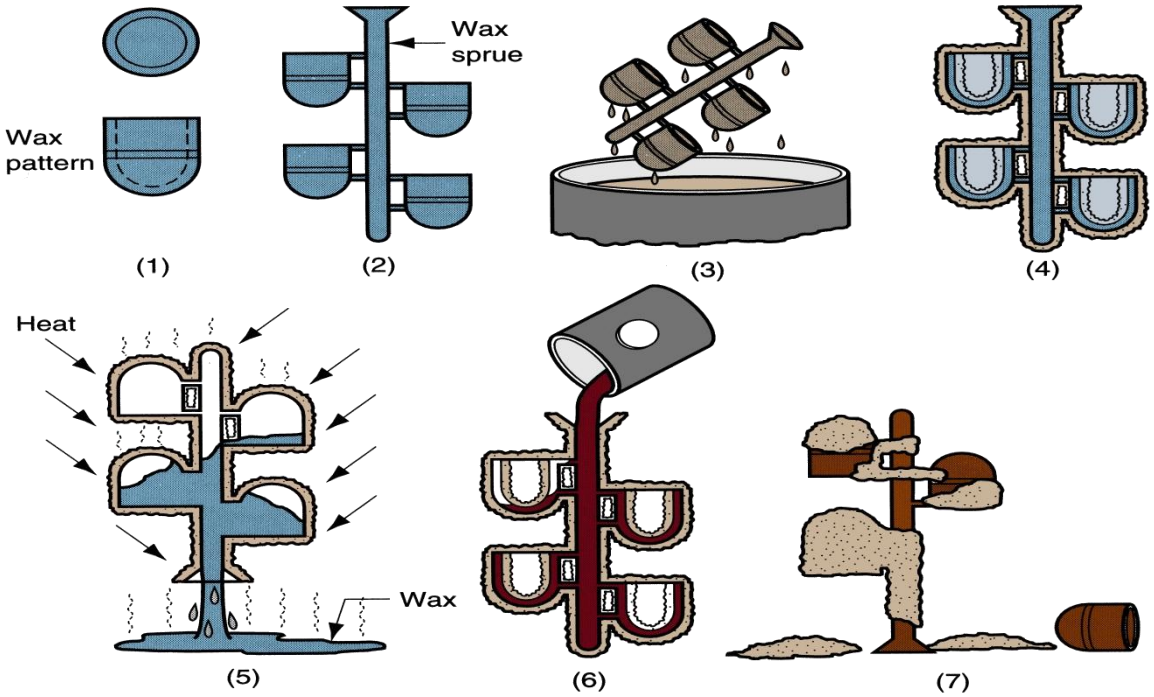
4.1.3 Vacuum Molding

- It uses a sand mold held together by vacuum pressure rather than by a chemical binder.
- It has advantages in case of using metal casting that is easy to be oxidation or absorb to gas.



4.1.4 Investment Casting

- A pattern made of wax is coated with a refractory material to make the mold, after which the wax is melted away prior to pouring the molten metal.
- The wax pattern is lost from the mold prior to casting.



4.2 Permanent Mold Casting Process

4.2.1 Basic Permanent Mold Process

- Metal mold constructed of two sections that are designed for easy, precise opening and closing.
- Metals commonly cast in permanent molds include aluminum, magnesium, copper-base alloys, and cast iron.
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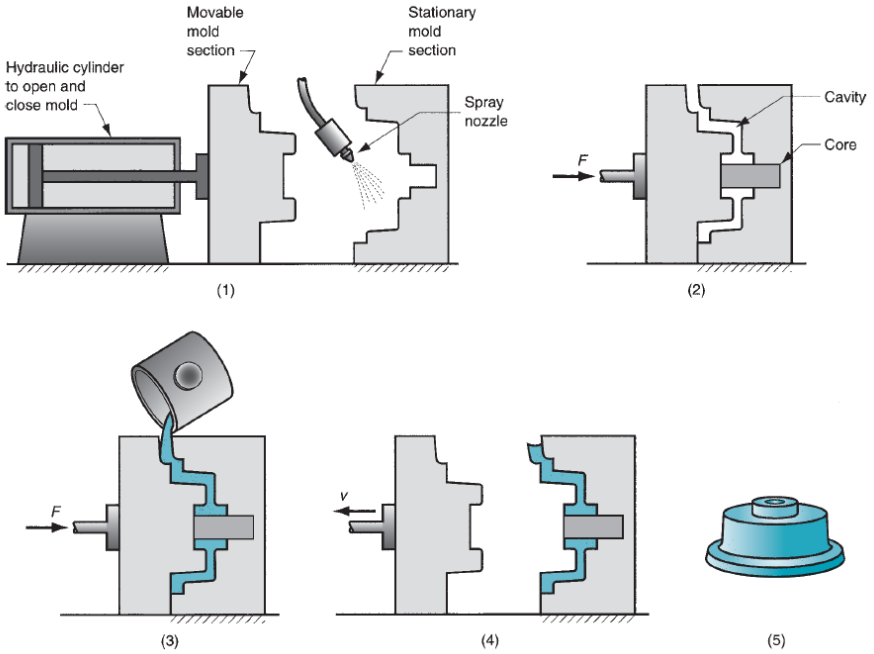
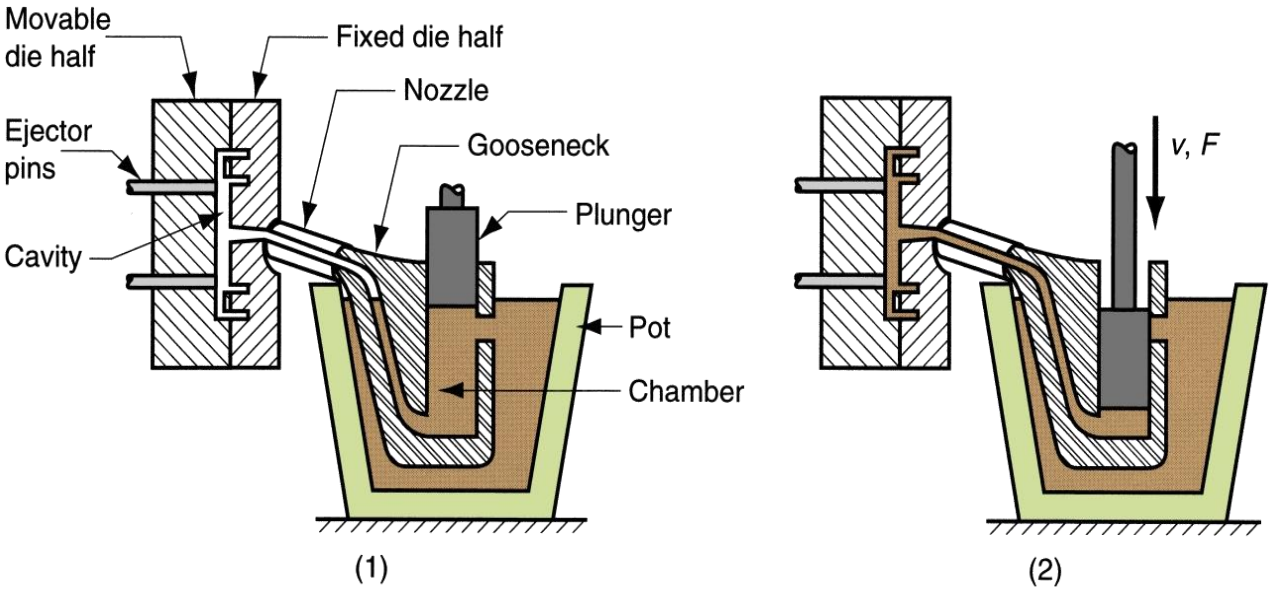


4.2.3 Die Casting

- The molten metal is injected into the mold cavity under high pressure.
- Typical pressures are 7 to 350 MPa (1015–50,763 lb/in2).
- The pressure is maintained during solidification, after which the mold is opened and the part is removed.
- Manufacturing of parts using die casting do not need another finishing process.



4.2.4 Centrifugal Casting

- Basically used centrifugal force. that is typically used to cast thin-walled rotating cylinders.
- It is noted for the high quality of the results attainable, particularly for precise control of their metallurgy and interior structure without void.
- Cooling rate is so fast that interior structure is fine and compact.

$$C = \frac{W}{3g}\omega^2\left(r_1^2 - \frac{r_2^3}{r_1}\right) \quad g/cm^2$$

W :
ω :
r_1 :
r_2 :

$$N = \frac{K_0}{\sqrt{r}} \quad rev/\min$$

K_0:
r :

※ K_0 – **Cast Iron: 1800 ~ 2500**
Cast Steel : 2150 ~ 2730
bronze : 2000 ~ 2200
Al-alloy : 2900 ~3500
Ni-Cr Steel : 3400 ~4000

5. Crack in casting and eliminate residual stress

1) Defect ; Hot crack, Hot tear

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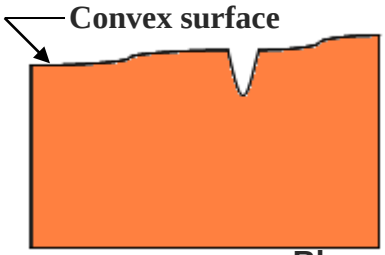
- In phase diagram, liquid is transformed to 50~90% of solid at next above solidus line (This area is mixed solid and liquid), meanwhile high temperature and fast cooling rate can be caused residual stress and hot crack in casting process.
- Hot crack usually occur in casting which contain a lot of impurities such as S and P

2) Bubble flaw

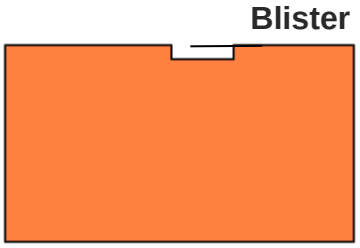
① Blow :

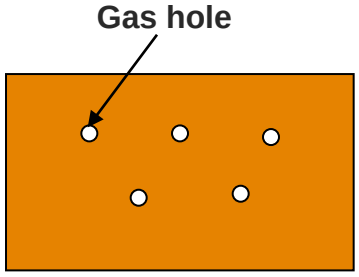
② Scar : It occur at surface, and shallow



③ Blister :

④ Gas hole : Existing gases in casting materials make bubble holes.





⑤ Pin hole : Bubble flaw in casting surface or subsurface.
Pin hole is even size distribution in the casting surface.

⑥ Porosity : Porosity or void fraction is a measure of fine void (i.e., "empty") spaces in a material